REPORT NO T5/83

A BIOPHYSICAL EVALUATION OF AN EVAPORATIVELY-COOLED WATER BAG

U S ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

Natick, Massachusetts

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Commercially available flax canvas water bags were evaluated for their ability to cool drinking water by evaporating water from their outer surfaces. Evaluations were conducted in an environmentally-controlled chamber under various climatic conditions. Different ambient temperatures, relative humidities and wind velocities were utilized to create climatic conditions normally observed in Southwest Asia during the summer months (June through September). Water which was initially above or below ambient temperature approached an equilibrium temperature (T_{eq}) in the water bag which was at or near the chamber

wet-bulb temperature (T_{WB}) in 2 to 5 hours, depending on the wind speed. High wind velocities (WV) over the water bags were responsible for large total water volume losses which could be significant in a combat situation involving extended desert maneuvers in remote regions.

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by

Thomas L. Endrusick, John R. Breckenridge and Ralph F. Goldman, Ph.D.

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Abstract

Commercially-available flax canvas water bags were evaluated for their ability to cool drinking water by evaporating water from their outer surfaces. Evaluations were conducted in an environmentally-controlled chamber under various climatic conditions. Different ambient temperatures, relative humidities and wind velocities were utilized to create climatic conditions normally observed in Southwest Asia during the summer months (June through September). Water which was initially above or below ambient temperature approached an equilibrium temperature (T_{eq}) in the water bag which was at or near the chamber wet-bulb temperature (T_{wb}) in 2 to 5 hours, depending on the wind speed. High wind velocities (WV) over the water bags were responsible for large total water volume losses which could be significant in a combat situation involving extended desert maneuvers in remote regions.

Introduction

With the increase of political and social unrest in Southwest Asia, the future occurrence of armed conflict is a distinct possibility for some of the world's nations whose economies are undeniably dependent on that area's vast oil reserves. As a result of the widespread instability, the US Army is reviewing and testing equipment designed for desert operations. As part of this program the Biophysics Branch of the Military Ergonomics Division, USARIEM, received a request from the US Army Mobility Equipment Research and Development Command (USAMERADCOM), to evaluate the water cooling capabilities of a series of commercially-available water bags. Similar water bags are used extensively by the US Forest Service (USFS), to provide their firefighters with adequate drinking water in the remote areas where large forest fires occur.

Afaf (1) reports that the Pakistani Army utilized water bags constructed with inferior materials during their war with India in 1960. The volume of water these bags allowed to leak was considered excessive. Studies conducted in Pakistan in the post-war years confirmed the fact that the only successful material used in water bag construction so far has been a flax canvas. A water bag constructed of an impervious, rubberized material with sealed seams would solve the leaking problem inherent in canvas water bags but the cooling of the contained water requires the use of permeable materials which can wick water to the outer surface to be evaporated. Water containers fabricated from rubber and plastic materials often leave the water with an undesirable aftertaste. Rae (2), in studies conducted for the South African Bureau of Standards, investigated the possible use of combinations of man-made and natural fibers but the results did not show a substantial advantage over the pure flax canvas.

The fact that flax is not indigenous to the Pakistani region prompted Afaf to study the use of callendered fabrics in water bag construction. This is a

process where a thin coat of plasticized material is applied to the material creating an impervious barrier. In the Pakistani studies, the thickness of the plastic layer was reduced to a point where only the interstices between the threads of the fabric were filled. This process left the actual threads of the material free from plasticized coating, allowing an acceptable degree of water vapor transmission and percolation in a capillary manner.

This study will investigate the following physical functions of a water bag: the length of time for the water to achieve temperature equilibrium with its environment; the influence of the environment on the amount and rate of cooling and heating of the water; the quantity of water consumed or lost by drip in the evaporative-cooling process.

The availability of flax canvas water bags within the United States assures their continued use and creates this need to define the physical capability of the bags to provide adequate quantities of potable water to mobile troops engaged in extended desert operations.

Methods and Materials

Experiments were conducted in an environmentally-controllable chamber with a temperature range of -1 to 66°C (30 - 150°F). Meteorological conditions normally observed in Southwest Asia during the summer months (June through September), were simulated by strict control over the ambient temperature, relative humidity and wind velocity. Various wind velocities on the bags were produced by two fans and adjustment of the locations of the water bags in their zones of influence; average chamber air motion out of the mainstream of fan air flow was 0.5 m/s, up from the usual 0.2 m/s when the fans were not used. Relative humidity inside the chamber was monitored with an electric hygrometer indicator (Hygrodynamics Inc.). Each of the three test water bags was fitted

with thermocouples constructed of 24 gauge copper and constantan wire. Three thermocouples were attached to each bag at the following sites: submerged inside the bag approximately two inches from the bottom; centered on the outside surface of the bag facing the wind, if any; and centered on the outside surface of the bag away from the wind source. The two thermocouples for monitoring outside surface temperature were attached to the bags by simply stapling them to the flax canvas. Periodic checking of these two thermocouples ensured that complete contact between the bag surface and the thermocouple was maintained.

The water bags were suspended from the ceiling in separate corners of the chamber. On each test day the three bags were usually exposed to three different wind speeds: calm air (influence of chamber air motion only); intermediate wind speed (1.4 - 3.4 m/s); and high wind speed (3.4 - 6.6 m/s).

Thermocouple temperatures were recorded every minute during the entire test period using a Leeds and Northrup Speedomax recorder. Accurate measurement of the ambient temperature inside the chamber was done by the use of two additional thermocouples that were connected to the Leeds and Northrup recorder. One thermocouple was located approximately 0.5 m (18 in) below the ceiling of the chamber and the second was located 0.17 m (6 in) above the floor of the chamber. The average of these two thermocouples was used as the ambient temperature inside the chamber.

All three water bags were soaked overnight between test days to ensure uniform, maximal saturation and swelling of the canvas before testing. Each water bag was filled with water and immediately weighed to the nearest gram on a Sauter electronic platform scale. The volume of water lost by each bag through the process of dripping was collected in large basins positioned under each bag. This procedure was not followed at the start of the study. However,

when it became apparent that drip losses were going to be substantial during certain environments, drip loss measurements were started. Evaporation of this drip volume was minimized by the addition of a small volume of mineral oil to the collection basin.

When the water in each water bag appeared to hold steadily at an equilibrium temperature the test for that particular water bag was terminated. The water bag was then immediately removed from its ceiling suspension and weighed to the nearest gram. The final volume and the collected drip volume were measured to the nearest milliliter. These values were used to calculate the percentage of water lost through dripping, the percentage of water lost through evaporation, the volume of water lost per hour through dripping and the volume of water lost per hour through evaporation.

Climatic Categories

Three climatic categories were simulated in the controllable test chamber. These three different environments were chosen to represent typically occurring climatic conditions found in Southwest Asia in the summer months. The three climatic conditions chosen are among eight environments defined in Army Regulation 70-38, (Research, Development, Test and Evaluation of Materiels for Extreme Climatic Conditions) (3).

Category 3, referred to as Humid-Hot Coastal Desert, is found along the immediate coasts of large bodies of water having high surface temperatures. Areas in this category located in Southwest Asia would be found in a belt of land approximately 150 miles wide circling the Persian Gulf and both eastern and western shores of the southern half of the Red Sea. These areas experience the highest percentage of water vapor at ground level reported anywhere in the world. Operational conditions for Category 3, as defined in AR 70-38, are a range of ambient air temperature between 29.5 - 37.8°C (85-100°F), a range of

solar radiation of 0 - 1135 watts/m^2 (0-360 Btu/ft^2 hr) and a range of ambient relative humidity between 63-90%.

Category 4, Hot-Dry, occurs in eastern Saudi Arabia, large portions of Iraq, small, interior portions of Iran, Afghanistan, and the entire interior of India. Operational conditions in this category are defined as having ranges of ambient air temperature of 32.2-52.1°C (90-125°F), solar radiation of 0-1135 watts/m^2 (0-360 Btu/ft^2/hr), and ambient relative humidity of 5-20%.

Category 5, Intermediate Hot-Dry, is found in western Saudi Arabia and in the majority of Iran, Afghanistan, Yemen, Jordan, Israel, Palestine, Lebanon, Syria and Oman. Operational conditions here are ambient air temperatures from 21.1-37.8°C (70-100°F), solar radiation of 0-1135 watts/m^2 (0-360 Btu/ft^2/hr) and relative humidity of 20-85%.

Environments from these three categories were simulated to study the physical effects on the water in the flax canvas bags. An applied solar load was not used in this study.

Theoretical Considerations

An analysis of energy exchange between a water bag and its environment suggests that water in the bag will tend to approach a temperature which approximates the wet-bulb temperature of the ambient air. Like a wet-bulb thermometer, the outer surface of the bag is wet and losing heat to the surrounding air by evaporation. This dissipation of heat lowers the surface temperature of the bag, which will cause heat to flow from the air to the bag by convection; net long-wave radiative heat gain from the surroundings also will increase as a result of the depressed temperature at the bag surface. For a wet-bulb thermometer, which has little mass or heat capacity, temperature equilibrium is reached rapidly; the bulb temperature merely has to fall

sufficiently to make the evaporative heat losses equal to the convective plus radiative heat gains. However, a filled water bag takes much longer to reach equilibrium because the heat capacity of the system is high. As the temperature of the water falls, the heat removed must be dissipated from the bag surface by evaporation, which can occur only at a limited rate determined by the vapor pressure of water in the air and the wind velocity over the bag surface (evaporation will be highest with low air vapor pressure and high wind).

The heat balance equation for both the wet-bulb thermometer and for a filled water bag, once its contents have reached a steady temperature, is

$$H_e = H_c + H_r \qquad \text{Equation 1}$$

where H_e = evaporative heat loss, W/m^2

H_c = convective heat gain from the environment, W/m^2

H_r = net radiant heat gain from the surroundings, W/m^2

Simply stated, the evaporative heat loss equals the sum of the convective and radiative heat gains. The evaporative and convective components in this equation both depend, among other factors, on the convective heat transfer coefficient h_c for the air moving past the thermometer or water bag. That is,

$$H_e = 2.2\, h_c\, (P_s - \phi_a P_a) \qquad \text{Equation 2}$$

and

$$H_c = h_c\, (t_a - t_s) \qquad \text{Equation 3}$$

where h_c = convective heat transfer coefficient, $W/m^2\ {}^{\circ}C$

P_s = saturated vapor pressure at the wet surface, mm Hg

P_a = saturated vapor pressure of ambient air, mm Hg

ϕ_a = air relative humidity, percent

t_s = temperature of the wet surface, $^{\circ}C$

t_a = temperature of the ambient air, $^{\circ}C$

The factor 2.2 ($^{\circ}C$/mm Hg) is the ratio at sea level of the evaporative heat transfer coefficient h_e and the convective coefficient h_c, i.e.,

$$h_e = 2.2\, h_c \qquad \text{Equation 4}$$

The coefficient h_e can be expressed in W/m^2 mm Hg. This equation, known as the "Lewis Relation", indicates the common influence of air motion on both convective heat exchange and water vapor transport from a wet surface to the ambient air.

The term H_r in equation 1 may be determined from the Stefan-Boltzmann equation for radiant exchange, namely,

$$H_r = \varepsilon \sigma \, (T_r^4 - T_s^4) \qquad \text{Equation 5}$$

where ε = emissivity of the thermometer cover or water bag, percent

σ = Stefan constant, 5.67×10^{-8} $W/m^2 K^4$

T_r = temperature of the surroundings (absolute), kelvin

T_s = surface temperature (absolute), kelvin

To simplify this theoretical development, it will be assumed that the temperature of the surroundings equals air temperature, permitting equation 5 to be written as

$$H_r = \varepsilon \sigma \, (T_a^4 - T_s^4) \qquad \text{Equation 5a}$$

This equation may be expressed in a linear form which is more convenient to handle,

$$H_r = h_r' \varepsilon \, (t_a - t_s) \qquad \text{Equation 5b}$$

where h_r' = blackbody radiation exchange coefficient, determined at the average of t_a and t_s, $W/m^2 \, ^oC$

t_a = air or surroundings temperature, ^oC

t_s = surface temperature, ^oC

The coefficient h_r', which varies with temperature, is obtained by equating the linear and exact (Stefan-Boltzmann) forms of the radiation exchange equation, i.e.,

$$h_r' \, (t_a - t_s) = (T_a^4 - T_s^4) \qquad \text{Equation 6}$$

where σ = Stefan constant, $5.67 \times 10^{-8} W/m^2K^4$

T_a = air temperature (absolute), kelvin

T_s = surface temperature (absolute), kelvin

The coefficient h_r (equal to $h_r'\epsilon$) for the thermometer or water bag (assuming an emissivity of 0.9 for their surfaces) is $0.9\ h_r'$ or 5.7 W/m^2 °C for an average temperature (wet surface and surroundings) of 30°C: at 40°C average temperature, h_r increases to 6.3 W/m^2 °C.

The slopes of the lines of constant wet bulb temperature on a psychrometric chart (Fig. 1) are practically constant and have a value of 0.5 mm Hg per degree Celsius temperature difference. This constancy merely reflects the heat balance for a psychrometric wet bulb thermometer (i.e. one slung to produce air motion past the bulb of at least 3 m/s) as given by Equation 1, and the relation between h_c and h_e; the slope is 0.5 mm Hg/°C (i.e. 2°C/mm Hg) rather than the 2.2°C/mm Hg in the Lewis relationship because of radiant heat gain at the evaporatively cooled surface.

The expression for this slope is obtained by combining Equations 2, 3 and 5 with Equation 1; this gives:

$$(h_c + h_r)(t_a - t_s) = 2.2\ h_c\ (P_s - \phi_a P_a) \qquad \text{Equation 7}$$

or

$$\text{slope} = \frac{P_s - \phi_a P_a}{t_a - t_s} = \frac{h_c + h_r}{2.2 h_c} \qquad \text{Equation 8}$$

By treating the wet bulb thermometer as a 1 cm diameter cylinder and applying the equation of Hilpert (4),

$$h_c = \frac{kC(Re)^n}{d}$$

where h_c = convective heat transfer coefficient

k = thermal conductivity of air

d = cylinder diameter

Re = Reynolds number

C and n = constants determined by the Reynolds number

we obtain a value for h_c= 54 W/m^{2o}C at 38^{o}C air temperature. At 50% relative humidity, the average of the wet bulb temperature (28^{o}C) and 38^{o}C surroundings is 33^{o}C and h_r has a value of 5.8 W/m^{2o}C, which is about 10% of h_c. The ratio h_c/h_r remains practically constant over a wide temperature range if there is sufficient air motion (3 m/s) over the bulb, thus accounting for the almost constant slope of wet-bulb temperature lines. That is:

$$\text{Slope} = \frac{P_s - \phi_a P_a}{t_a - t_s} = \frac{h_c + h_r}{2.2h_c} = \frac{h_c + 0.1h_c}{2.2h_c} = 0.5 \text{ mm Hg}/^oC$$

Air motion greater than 3 m/s will not greatly increase h_c. Even if h_c is increased by 50%, the ratio of h_r to h_c is reduced to only 0.06, and the slope becomes 1.06/2.2 = 0.48, a relatively unimportant change. Thus, the speed of whirling the wet-bulb thermometer is not critical provided the prescribed minimum is observed.

The convective heat exchange coefficient for the water bag, which is much larger in size (i.e., greater diameter), is not so readily increased by air motion. In effect, the water bag behaves like a wet-bulb thermometer which is inadequately ventilated. If we treat it as a cylinder 0.3 m (1 ft) in diameter, the convective heat exchange coefficient in a 3 m/s wind at 38^{o}C is only 13.8 W/m^{2o}C (using Hilpert's equation), compared to 54 W/m^{2o}C for the wet bulb thermometer. The coefficient h_r is independent of the object size and can be assumed to have the same value as for the thermometer i.e., 5.8 W/m^{2o}C. Thus, the "constant wet-bulb temperature line" for the water bag in a 38^{o}C, 50% relative humidity environment has a slope given by,

$$\frac{P_s - \phi_a P_a}{t_a - t_s} = \frac{h_c + h_r}{2.2h_c} = \frac{13.8 + 5.8}{2.2 \times 13.8} = 0.65 \text{ mmHg}/^oC$$

The slopes of the "wet-bulb temperature" lines for the water bag are not as independent of temperature as they are for a psychrometric wet bulb thermometer; since h_c is smaller, changes in h_r with temperature have more effect on the slope. For example, at 50°C, h_c has a value of 13.2 W/m^2°C (down from 13.8 at 38°C). Assuming 20% relative humidity (28°C wet-bulb temperature and a probable bag surface-surroundings average temperature of 40°C), h_r would have a value of 6.3 W/m^2°C, (up from 5.8 W/m^2°C at 30°C and almost half of h_c). These changes would increase the slope of the "wet bulb" line for 50°C, 20% relative humidity to 0.67, or about 3% for an air temperature increase from 38°C to 50°C. This change in slope would accelerate at higher temperatures since h_c would continue to fall while h_r would rise.

As shown in Figure 1, the "wet bulb temperature" lines for a water bag in either a 38°C, 50% relative humidity environment or a 50°C, 20% relative humidity environment intercept the saturated vapor pressure line at temperatures above those for a psychrometric wet bulb, i.e., the wet-bulb temperatures for these environments. This will be true for any "wet bulb" temperature line with a slope greater than the 0.5 mmHg/°C, value for a psychrometric wet bulb thermometer. From Figure 1, it can be deduced that the minimum temperature which can be obtained by a water bag in a 38°C, 50% relative humidity environment with 3 m/s wind is 29.3°C, or 0.6°C above the air wet bulb temperature; at 50°C, 20% relative humidity, the water bag equilibrium temperature is 30.0°C, or 1.3°C above wet-bulb temperature. This elevation above wet bulb temperature depends on two factors, namely (1) the extent of the change in slope of the "wet bulb line" for the water bag and (2) the air relative humidity. The lower the humidity, the greater will be the influence of the line slope; at 100% humidity, the water bag will equilibrate at the air wet bulb temperature regardless of the slope.

A water bag and its contents will equilibrate at a much higher temperature with low air movement around the bag since the convective coefficient h_c will be reduced while h_r remains essentially unchanged. For example, calculations show that a bag in a 50°C, 20% relative humidity environment with 0.5 m/s air motion will have a convective exchange coefficient of only 4.2 W/m^2°C, resulting in a slope for the "wet-bulb" line through 50°C, 20% RH of 1.14 mmHg/°C. The corresponding intercept with the saturated vapor pressure curve (i.e., the "wet-bulb" temperature for the water bag under these conditions) occurs at 33°C or about 4°C above the air wet-bulb temperature. However, even under these low wind conditions, water could be cooled to 17°C below ambient temperature.

Up to this point, no account has been made of the heating effect of solar radiation on the water bag; in essence, this means that the predictions of equilibrium water temperature which have been made apply only for a bag in heavy shade, or in an indoor environment (as in the present study). However, the effects of sunlight can be estimated rather easily by treating it as a second radiant heat source on the bag and including it in the H_r term of the heat balance equation (Equation 1). If R is the solar radiation intensity (average) on the bag in W/m^2, this heat balance may be expressed as

$$2.2h_c (P_s - \phi_a P_a) = h_c (t_a - t_s) + h_r (t_a - t_s) + R$$

and the slope of the "wet bulb" line for a given environment is given by

$$\frac{P_s - \phi_a P_a}{t_a - t_s} = \frac{h_c + h_r + \frac{R}{t_a - t_s}}{2.2h_c}$$

On a relatively clear day, the combined direct and diffuse solar radiation on the water bag (assumed to be a 0.3 m diameter cylinder) is on the order of 150

W/m^2. Accordingly, calculations for a 50°C, 20% relative humidity environment with a 3 m/s air motion predict a "wet bulb" temperature for the water bag and contents (i.e., water equilibrium temperature) of about 31.7°C, or 1.7°C higher than with no sunlight (and 3°C above the psychrometric wet bulb temperature). The slope of the "wet bulb" line in this instance is increased by sunlight from 0.67 to 0.95. For a low air movement of only 0.5 m/s (h_c reduced to 4.2 $W/m^{2o}C$), the solar radiation load becomes relatively more important and the slope of the "wet bulb" line is greatly increased. For this example, the slope is given by

$$\frac{P_s - \phi_a P_a}{t_a - t_s} = \frac{4.2 + 6.3 + 12.5}{2.2 \times 4.2} = 2.51 \text{ mmHg}/^{o}C$$

The comparable value of the slope without sunlight was less than half as great (1.14 mmHg/°C); the predicted water equilibrium temperature was 33°C without sunlight and 38°C (9.3°C above air wet-bulb temperature) under a solar load.

Results and Discussion

Figures 2 through 4 represent three selected test days out of a total of 13 test days conducted during this study. Tables 1 through 3 contain physical data pertaining to all 13 test days.

Figure 2, which is day 2 data, shows the rise in the temperature of water (T_w) in a water bag as a function of time measured in minutes. Table 1 shows that on day 2, the initial temperature of the water (T_{wi}) was lower than the wet bulb temperature (T_{wb}) measured in the chamber. This afforded the opportunity to study the water bags' capability to keep cold water below T_a and the influences that wind velocity (WV) and relative humidity (% RH) have on this capability. It is unlikely that the water bags would be filled with cold tap water

immediately prior to an actual desert combat opeation as was done here. Nevertheless, the variability of day and night ambient temperatures in desert environments could cause the water in a water bag to be at a temperature several degrees lower than the T_a in the early morning hours.

Figure 2 shows a rapid approach of bags a and b toward wet bulb temperature. Both water bags were subjected to wind and reached T_{eq} in approximately 2 hrs. The final water temperatures (T_{wf}) of bags a and b were 28.0°C (82.4°F) and 27.2°C (81.0°F), respectively. These temperatures were slightly below the measured chamber T_{wb} of 29.5°C (85.0°F). Bag C, which was exposed only to chamber air motion (0.2 m/s) attained a T_{eq} of 29.5°C (85.0°F) in approximately 4 hrs. This T_{eq} was also the measured T_{wb} of the ambient air during test day 2. Table 1 shows that on day 2, the Hot-Dry conditions accounted for substantial water volume losses through evaporation, especially when wind is applied to the water bag. From the same Table it appears that when T_{wi} is below T_{wb} the Humid-Hot Coastal Desert conditions caused an increase in water volume loss through dripping. The Intermediate Hot-Dry conditions caused nearly equal losses through both evaporation and dripping.

Table 1 also shows that higher WV (> 3.4 m/s), usually caused larger water losses measured as a percent through evaporation.

Figure 3, data collected on test day 11, shows the time course of a water bag where T_{wi} was higher than the T_{wb} measured in the chamber. Water bags a and b which were exposed to WV of 3.1 and 5.1 m/s, respectively, reached T_{eq} in approximately 2 hours. This T_{eq} of 27.3°C for both bags was below the T_{wb} of 30.0°C measured in the chamber. Water bag C, exposed only to chamber air motion, reached A T_{eq} of 29.6°C in approximately 3 hours.

Figure 4, data from test day 13, shows the time course for water bags where the T_{wi} was above and below T_{wb}. Table 3 shows that the total volume

water losses when WV near the bags was zero were relatively small in the extreme heat and low relative humidity of the Hot-Dry conditions.

The fact that there was a slight difference at times between the measured T_{wf} and the T_{wb} suggests inaccuracies in one of the measurement methods. This probably can be traced to the RH sensors of the Hygrodynamics instrument, which are known to lose some accuracy with age.

Future work will involve the construction of prototype water bags composed of waterproof, breathable materials such as Gore-Tex laminate. The result will hopefully be a water bag that does not leak under any climatic conditions and at the same time is capable of effectively cooling drinking water through the process of evaporation.

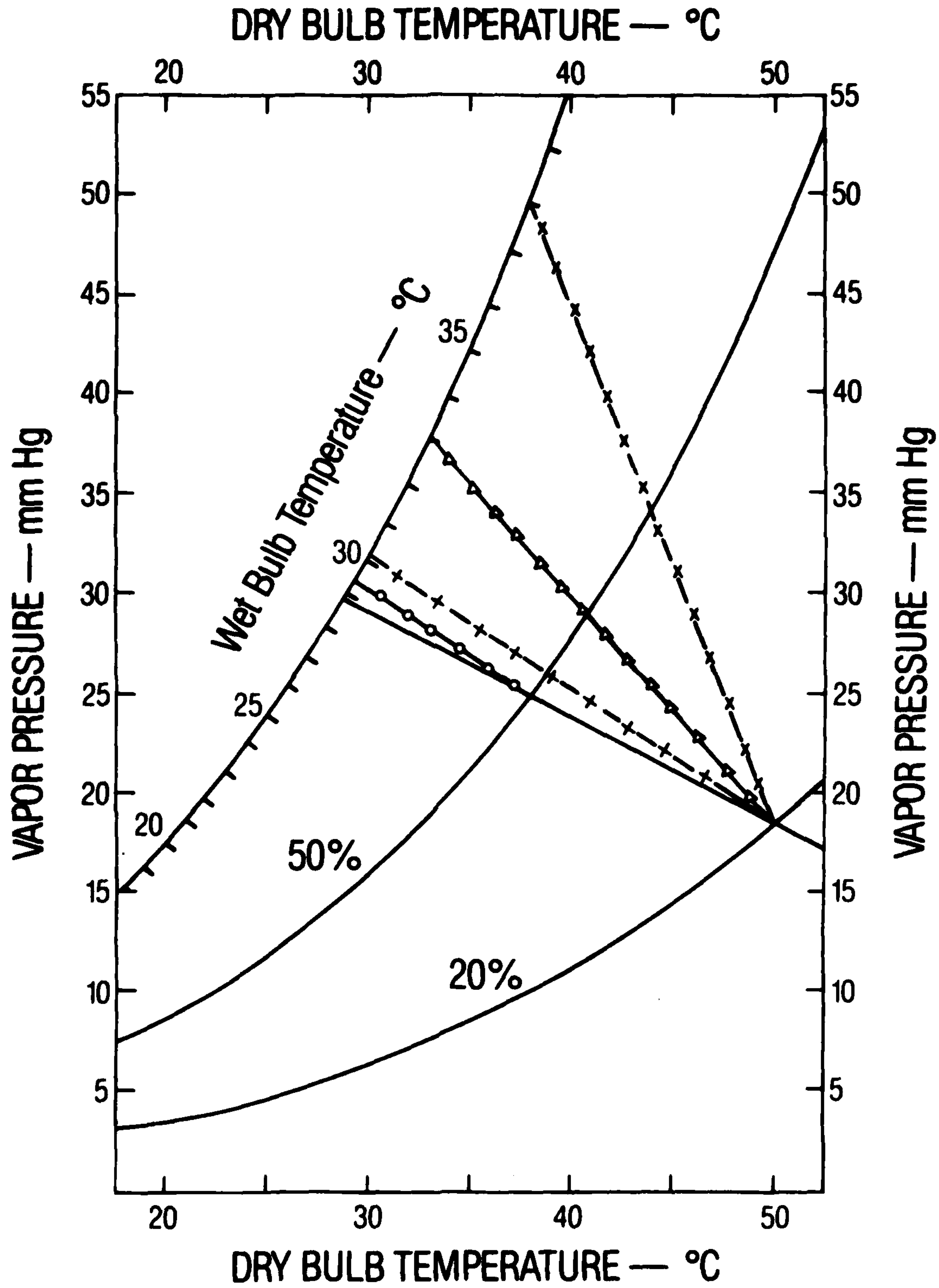

Figure 1. Predicted Elevation in Temperature of Unaspirated Water Bag

0-0 38°C, 50% RH, 3 m/s, no sun

+-+ 50°C, 20% RH, 3 m/s, no sun

o-o 50°C, 20% RH, 0.5 m/s, no sun

x-x 50°C, 20% RH, 0.5 m/s, sunlight

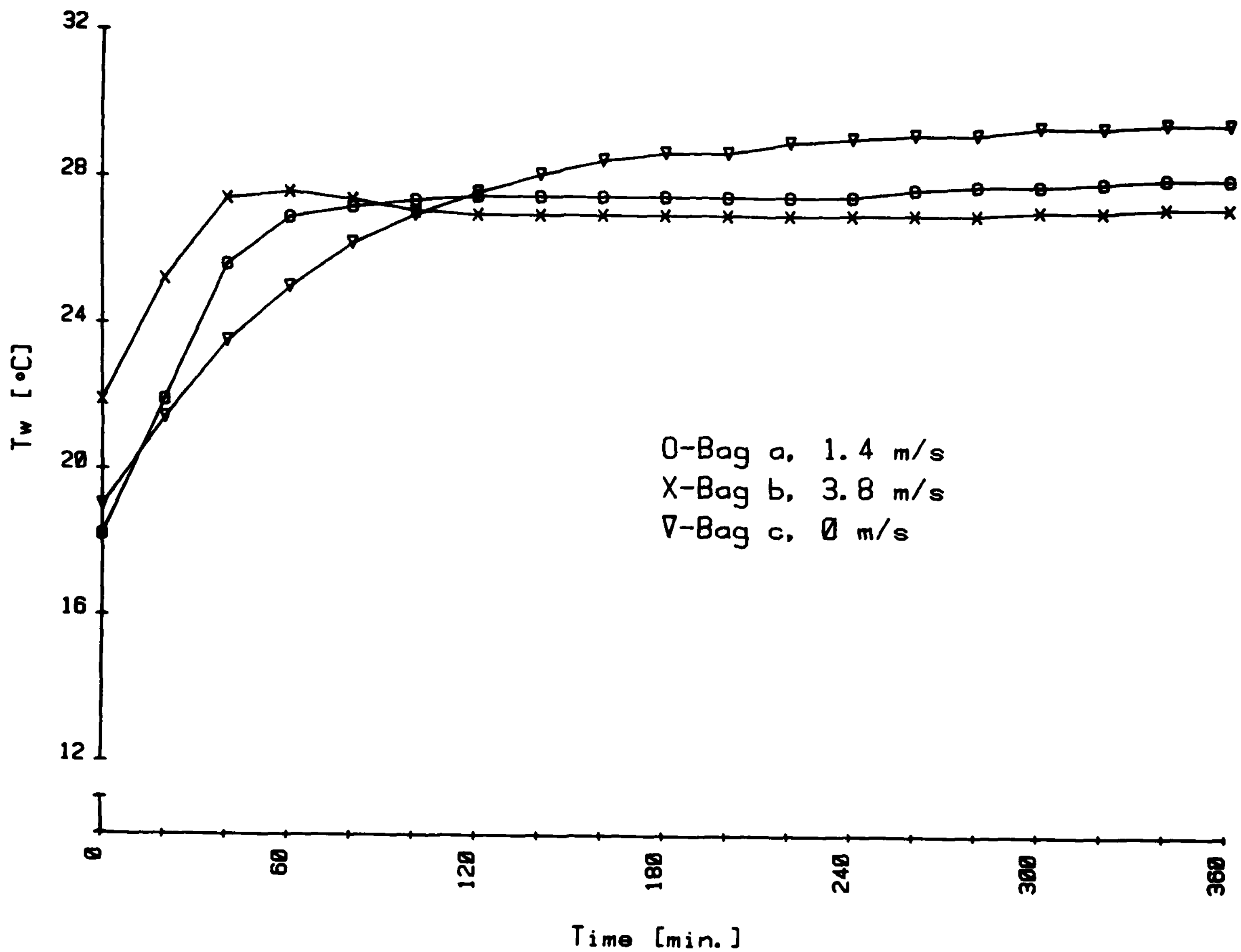

Fig. 2. Time course of Tw Day 2 Twb[°C] 29.5 RH[%] 25

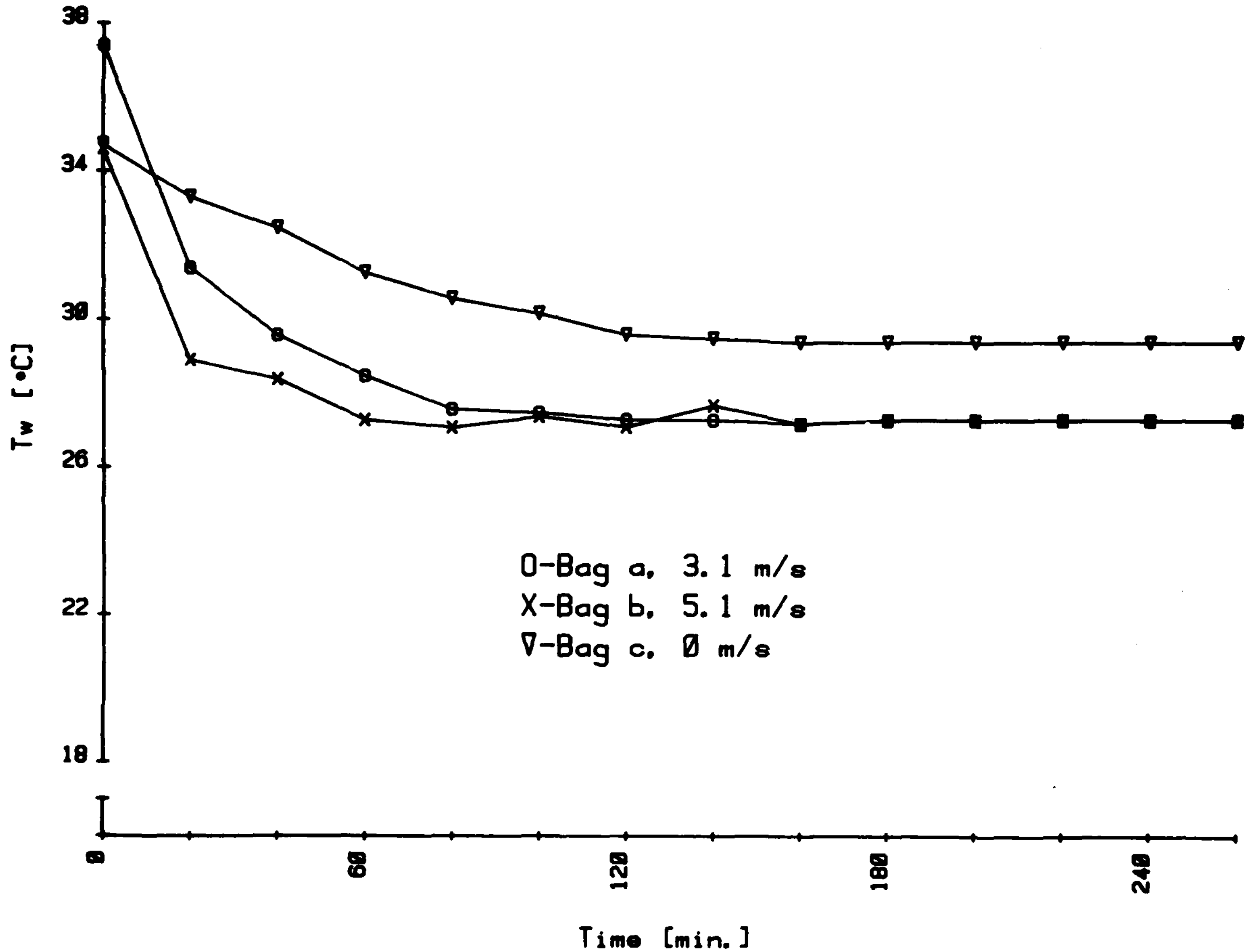

Fig. 3 Time course of Tw Day 11 Twb[°C] 30.0 RH[%] 54

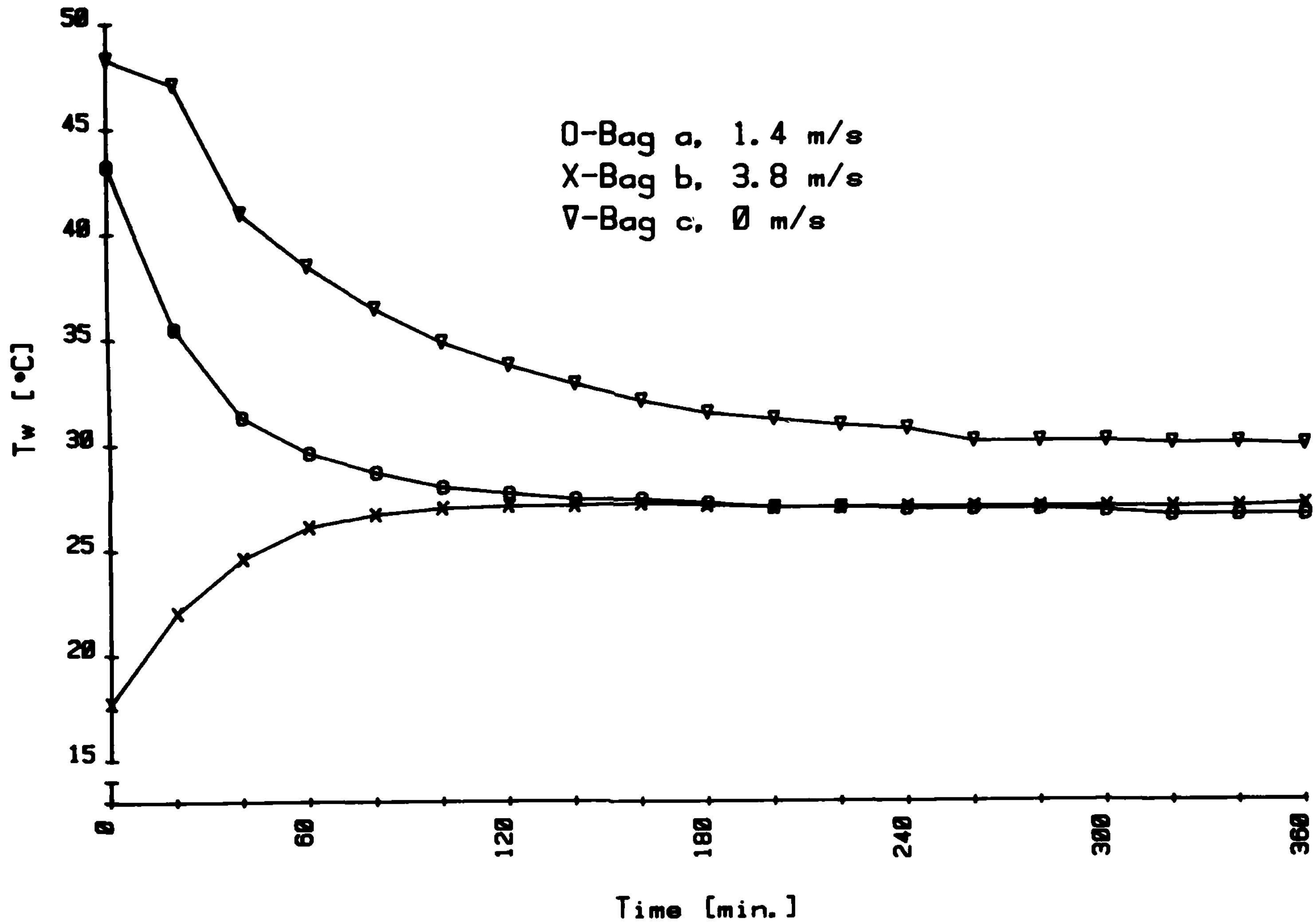

Fig. 4 Time course of Tw Day 13 Twb[°C] 3Ø.6 RH[%] 29

Table 1 T_{wi} Below T_{wb}

Day/ Bag	T_a °C	RH %	T_{wb} °C	WV m/s	*Climate Category (1)	T_{wi} °C	T_{wf} °C	Approx Time to T_{eq} hr	% Lost Dripping	% Lost Evapo-rative	Total Vol Lost ml
1 a	30.0	92	28.9	0.5	3	22.6	30.6	6	91	9	2854
b	30.0	92	28.9	2.0	3	17.5	28.4	6	72	28	2520
2 a	48.2	25	29.5	1.4	4	18.2	28.0	2	7	93	2010
b	48.2	25	29.5	3.8	4	21.9	27.2	2	13	78	1798
c	48.2	25	29.5	0.5	4	19.0	29.5	4	24	76	893
3 a	37.3	50	28.4	1.4	5	17.0	22.6	5	63	37	2933
b	37.3	50	28.4	3.8	5	18.1	25.2	5	42	58	5472
c	37.3	50	28.4	0.5	5	15.2	22.7	5	43	57	2003
4 a	37.9	25	22.5	3.4	5	23.1	23.7	5	55	45	2658
b	37.9	25	22.5	2.0	5	15.4	23.5	5	48	52	2855
c	37.9	25	22.5	0.5	5	15.5	24.8	5	82	18	2938
5 a	38.3	35	25.3	0.5	5	16.0	25.7	5	51	49	1000
6 a	38.5	22	22.2	6.6	5	21.2	23.0	2	22	78	2334
7 a	38.3	46	28.4	0.5	5	15.0	28.7	5	(2)	(2)	1120

(1) 3: Humid-Hot Coastal Desert
4: Hot-Dry
5: Intermediate Hot-Dry
(2) Measurements not taken

Table 2 T_{wi} Above T_{wb}

Day/ Bag	T_a °C	RH %	T_{wb} °C	WV m/s	*Climate Category (1)	T_{wi} °C	T_{wf} °C	Approx Time to T_{eq} hr	% Lost Dripping	% Lost Evapo-rative	Total Vol Lost ml
8 a	27.6	35	17.8	0.5	5	21.8	20.7	3	54	28	72
9 a	36.7	38	25.0	4.6	5	32.5	22.4	3	18	(2)	(2)
b	36.7	38	25.0	3.6	5	33.2	23.2	4	41		
c	36.7	38	25.0	0.5	5	32.7	25.5	4	23		
10 a	37.8	54	29.5	4.0	5	37.4	27.3	3	17		
b	37.8	54	29.5	2.8	5	34.6	27.3	2	8		
c	37.8	54	29.5	0.5	5	34.7	29.4	3	11		
11 a	38.2	54	30.0	3.1	5	33.3	26.8	2	14		
b	38.2	54	30.0	5.1	5	31.5	28.3	3	22		
c	38.2	54	30.0	0.5	5	33.2	29.6	3	12		

(1) 5: Intermediate Hot-Dry
(2) Measurements not taken.

Table 3 T_{wi} Above and Below T_{wb}

Day/ Bag	T_a °C	RH %	T_{wb} °C	WV m/s	*Climate Category (1)	T_{wi} °C	T_{wf} °C	Approx Time to T_{eq} hr	% Lost Dripping	% Lost Evapo-rative	Total Vol Lost ml
12 a	47.1	30	30.4	0.5	4	37.4	31.5	5	(2)	(2)	(2)
b	47.1	30	30.4	2.4	4	37.4	29.2	4			
c	47.1	30	30.4	0.5	4	17.7	29.9	4			
13 a	47.6	29	30.6	1.4	4	43.2	26.6	3			
b	47.6	29	30.6	3.8	4	17.7	27.1	3			
c	47.6	29	30.6	0.5	4	48.3	29.9	5			

(1) 4: Hot-Dry
(2) Measurements not taken.

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